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DEVELOPMENT OF A LOW-COST METEOROLOGICAL STATION TO MEASURE ESSENTIAL CLIMATE VARIABLES

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This work presents preliminary research on a low-cost meteorological station for measuring in situ Essential Climate Variables (ECV): solar irradiance, surface water vapour, surface air temperature, land surface wind speed/direction, and precipitation. Important benefits can be obtained from these data: 1) optimization of irrigation systems and water input into the crops, leading to a breakthrough in agriculture in countries lacking meteorological infrastructure; 2) improvement of climate change monitoring. Availability of time series of satellite, airborne and in situ observation data, covering at least several decades, is necessary to validate climate models, which provide essential information for supporting decision-making processes relating to climate change. The proposed station could bridge some of the existing gaps in acquisition of ECV data, and would allow for calibration and validation of satellite data and derived products. While in situ measurements are essential, Earth Observation satellites are the only realistic means to obtain the necessary global coverage. With well-calibrated space-based measurements thanks to data provided by the proposed station, space-based sensors would become a key tool for climate monitoring. 3) Availability of land surface wind speed/direction data measured during extended periods of time is essential for installation/optimization of wind turbines and for construction of an aerodrome runway in a given location. Thus, the proposed station could facilitate the diffusion of wind energy. The users of the proposed station would be governments, public administrations and institutions, public and private companies, NGOs, farmers, and transnational or intergovernmental organizations. Summarizing, widespread implementation of the proposed station in areas lacking meteorological infrastructure would bring more well-being to large groups of people, and foster a more sustainable development. The objective of this work is to present a pre-feasibility analysis of the proposed station, and to report a preliminary research on the best shelter design using computational fluid dynamics software. The criterion is the accuracy with which the surface air temperature is reproduced inside the shelter in extreme temperature and solar radiation conditions, with almost no wind and with moderately strong wind. A design based on recommendations by the World Meteorological Organization and a smaller design with identical geometry were analysed. Since the performance of the latter was better, two alternative designs of similar size were studied, all in three different materials (PVC, rubber and wood), with and without white paint coating. Shelters made of PVC or rubber instead of wood, and/or in alternative designs, are probably more interesting if other criteria are taken into account.

I. INTRODUCTION

Many regions in the Earth are lacking basic infrastructure necessary to measure interesting atmospheric parameters like surface air temperature, rainfall, or wind speed and direction. For developing countries, the high cost of commercial weather stations is the main cause impeding installation of a proper network of stations. This work presents preliminary research on a new concept of meteorological station. The ultimate goal is to develop a small-size, low-cost, robust meteorological station especially designed for (but not limited to) developing countries, and to meet the requirements and standards of the international

scientific community and international organizations as per research focused on the Earth system and climate change monitoring. The purpose of the station would be to measure in situ some Essential Climate Variables (ECV)¹. The priority is to measure the solar irradiance (hours of light H_L or net radiation R_S), the surface water vapour (relative humidity or water vapour pressure p_{H2O}), the surface air temperature, the land surface wind speed and direction, and finally the precipitation or rainfall. Special consideration will be given to study the feasibility of measuring also the surface air pressure, the atmospheric CH_4 and the atmospheric CO_2 . The interest of this project comes from the fact that important

benefits can be derived from acquiring the above mentioned data:

First identified benefit: The mentioned data is valuable for many industries and services worldwide. In particular, it can rapidly lead to a breakthrough in agriculture in countries lacking proper meteorological infrastructure [1]. The reason is that, with some of the above listed ECV, it is possible to estimate the evapotranspiration ET_0 , and the dew temperature with the psychrometric equation [2], enabling in turn the optimization of irrigation systems and water input into the crops. Consequently, agricultural production could be increased while saving water.

Second identified benefit: The proposed station is conceived to help in climate change monitoring. Monitoring, characterization and prediction of changes in the Earth system (and particularly the climate) are based on the availability of time series of satellite, airborne and in situ observation data, covering at least several decades. For instance, this is necessary to validate models of the Earth system and the climate, which provide essential information for supporting decision-making processes relating to climate change, etc. As recognized by the international community of organizations responsible for climate monitoring: 1) continuity of consistent, calibrated observations (especially of ECV) is the major requirement; and 2) calibration and inter-calibration of the time series of observation data and validation of their derived products is an absolute pre-requisite for the consistency and efficient use of these data [3]. In line with these requirements, the proposed meteorological station would:

- Bridge some of the existing gaps in acquisition of ECV, e.g., land surface wind speed/direction or surface air pressure (see Fig. 1). This problem affects all countries, but it is particularly important in developing countries².
- Allow for the vital calibration and validation of satellite data and derived products. While in situ measurements are essential (e.g., to obtain data that cannot be measured from space), Earth Observation satellites are the only realistic means to obtain the necessary global coverage. With well-calibrated space-based measurements thanks to in situ data provided by the proposed station, space-based sensors would become a key tool for climate monitoring.

Third identified benefit: Measurements of land surface wind speed and direction acquired during extended periods of time are essential for installation

and optimization of wind turbines, and also for establishing the appropriate orientation of the runway(s) of an aerodrome in a given location. Energy systems and services are essential to both social and economic development [3]. The current structure of the global energy system is not compatible with sustainable development [4], not only from the usual economic and environmental perspectives, but also for social reasons that receive much less attention. Much wider and greater energy inputs and access to energy services is critical in achieving the Millennium Development Goals. In particular, it is necessary to “provide access to modern energy services (in the form of mechanical power and electricity) at the community level for all rural communities” [3], because electricity contributes effectively to the improvement of living standards and well-being through services such as night lighting, access to information, communications, drinking water and sanitation, health and education, as well as by generating income and jobs. A low-cost meteorological station may enable widespread wind data acquisition both in developing and developed countries, and thus facilitating the diffusion of wind energy.

Implementation of the proposed station in areas of the Earth lacking proper meteorological infrastructure, or complementing already existing networks, may enable attaining one or more of the benefits exposed previously. The objective of this work is, on one side, to present a brief pre-feasibility analysis of the proposed meteorological station and, on the other side, to report a preliminary research to determine the best shelter design, as a first step in the overall design of the station. Following this introduction, Section II presents the pre-feasibility analysis. Section III shows the methodology used in this research. The results are presented and discussed in Section IV. In Section V, considerations on data storage and transmission are reviewed. Finally, the conclusions are exposed in Section VI.

II. PRE-FEASIBILITY ANALYSIS

A brief pre-feasibility analysis of the proposed meteorological station is presented in this section.

II.I Sectors to which the meteorological station is aimed and identification of potential clients

The proposed station may enable implementation of extensive meteorological networks, especially in developing countries. The data recorded by these stations would be valuable for many sectors of human activity (see Section I for some examples). In developing countries, availability of these data may enable also the flourishing and growth of new economic sectors, activities and services (already existing in developed countries or not), and would foster a more sustainable development.

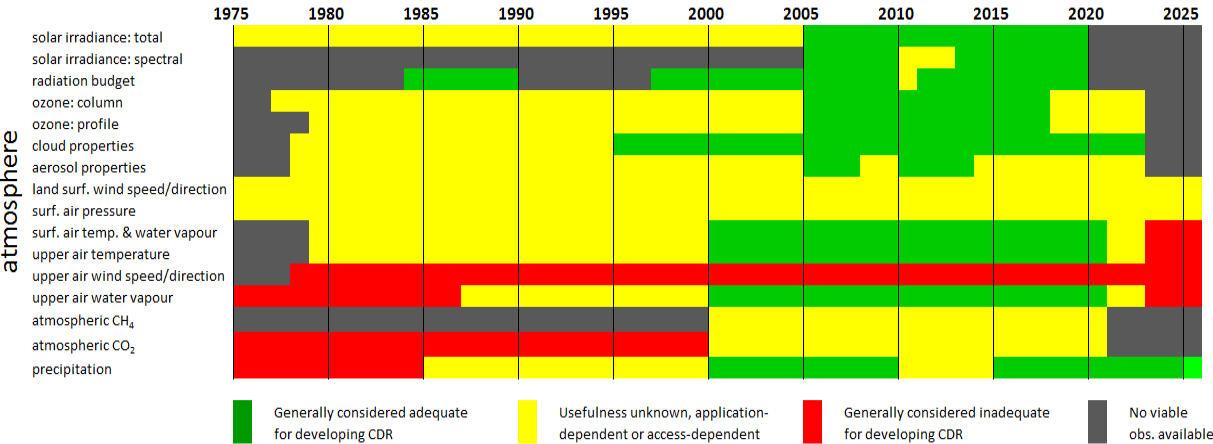


Fig. 1: Global atmospheric Essential Climate Variables (ECV) with heritage records, where CDR stands for Climate Data Records [3]. This information allows performing gap analysis for ECV data records from 1975 to 2025.

The potential users of the proposed station would be governments, public administrations and institutions, public and private companies, NGOs, farmers, and transnational or intergovernmental organizations like the Global Climate Observing System (GCOS), Food and Agriculture Organization (FAO), World Climate Research Programme (WCRP), World Meteorological Organization (WMO), etc.

II.II Situation of the market in relation to the proposed meteorological station

There is a wide variety of small meteorological stations in the market, generally able to acquire many types of data. These stations, supplied by large companies, are typically high-technology, high-performance products specially designed for the domestic and agricultural markets mainly in developed countries. These products are not generally thought for satisfying the needs of developing countries, and their high cost (ranging from 500 to 8000€ or more) does not match limited budgets. On top, many developing countries, facing at present day critical problems like famine, violence, diseases and degradation of the environment, aggravated by a persistent lack of resources, do not consider meteorology a priority. Therefore, the niche in these markets (which justifies the convenience of the proposed meteorological station and its potential) exists due to the high cost of the equivalent products (i.e., those commercial stations recording a minimum set of variables, included also among the ECV, and identified as key for agricultural purposes).

Moreover, there are no stations in the market especially designed to meet the requirements and standards of the international scientific community and

international organizations as per research focused on the Earth system and climate change monitoring. Thus, this is another promising gap (with no competence) that the proposed station would potentially fill. Summarizing, the station would feature a competitive advantage in potentially large markets like developing countries or in particular applications (e.g., for implementation of large networks to monitor climate change) by virtue of its specificities and its capacity to provide useful data at lower cost respect to equivalent commercial stations.

II.III Guidelines and milestones to obtain profitability

It is envisioned the proposed meteorological station to be supplied by a social enterprise, thus giving rise to an inclusive business, defined as an economically profitable initiative, featuring social and environmental responsibility, which will make use of capitalistic strategies and market mechanisms to fight poverty, improve human well-being, the society and/or environmental standards. Therefore, unlike for a conventional enterprise, profitability is critical only so as to ensure the long-term survivability of the company itself, in order for it to accomplish its philanthropic goals. To be considered a social enterprise, and thus to have access to or to be eligible for some of the associated advantages, the company providing the station will have to meet the particular requirements specified by target public administrations. Next follow some examples of such requirements:

- The price of the station should be incremental respect to the customer income, e.g., while for developed countries the unit price of the product would be adjusted to market prices, for developing countries the unit price could be

significantly lower than the market prices, and could even be lower than the manufacturing cost. The losses must then be counterbalanced with the fiscal advantages and financial incentives and support that social enterprises may be granted by public institutions and administrations, private foundations and donors, social banks, etc. and by funds raised from grants for cooperation and development projects, projects involving climate change fight, renewable energies, etc.

- Whenever possible, the station should involve members of the local community (e.g., local cooperation institutions, NGOs, administrations, families, etc.), which for instance will participate in the value chain:
 - as suppliers of prime materials, preferably local materials;
 - as manufacturers and/or agents that add value to the product; and
 - as sellers or distributors of the product, maintenance/customer service providers, etc., making easier and/or cheaper aspects like logistics, shipping, manufacturing, etc. and making the business more sustainable, user-friendly, etc.
- Whenever possible, the developers will strive for the station to enable access of developing countries to new business opportunities and ways to improve well-being based on the product.

The United Nations Framework Convention on Climate Change (UNFCCC) calls for support to programmes, networks, and organizations in defining, conducting, assessing, and financing research, systematic observations and strengthening of systematic observation and research capacity (in particular in developing countries). The Global Earth Observation System of Systems (GEOSS) supports the development of observational capabilities for ECV identified by the international scientific community affiliated with GCOS as necessary to understand climate change [3]. Thus, either the UNFCCC or the GEOSS or both may support the development and implementation of the proposed meteorological station.

III. METHODOLOGY

A suitable approach and realistic and standardized input data are required to obtain profitable results from the proposed research. The approach consists of the analysis procedure, applicable standards, software tools, studied cases, etc. while the later refer to shelter specifications, atmospheric conditions, etc.

III.I Analysis procedure

Fig. 2 shows a flow chart of the general procedure when performing Computational Fluid Dynamics (CFD) analysis. In particular, the procedure followed in this research consists of these steps:

1. Creation of the 3D geometries of the studied shelter designs with a commercial Computer Aided Design (CAD) software package.
2. Creation of the 3D meshes for the studied shelter designs with a commercial CFD and thermal analysis software package.
3. Definition of the criterion to establish the goodness of the studied shelter designs and thus to determine the best design.
4. Definition of the physics of the problem and the boundary conditions.
5. Solving of the fluid dynamics and thermal problem with the solver.
6. Post-processing and analysis of the results obtained for each studied shelter design:
 - i. characterization of the performance of each design; and
 - ii. determination of the best design according to the established criterion.

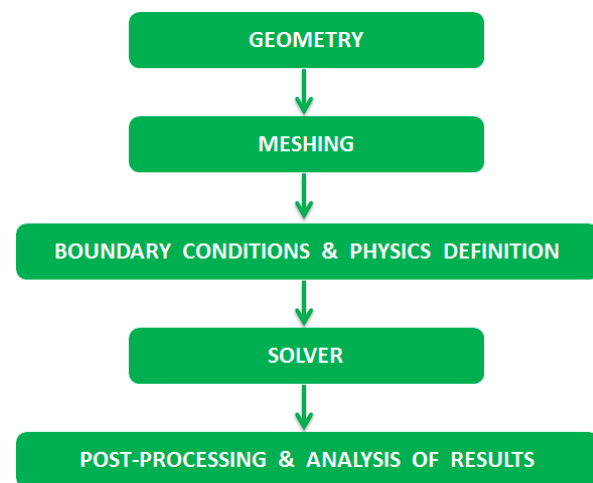


Fig. 2: Computational Fluid Dynamics (CFD) analysis flow chart [4].

III.II Software tools

Two software tools have been used in this research:

1. **Solid Edge:** This is a commercial 2D/3D CAD software package from Siemens PLM Software, Munich (Germany), for design of complex pieces or assemblies of pieces. It was used to generate the 3D geometries of the studied shelter designs.
2. **SolidWorks:** This is a commercial CAD design software package from Dassault Systèmes

SolidWorks Corp., Waltham, Massachusetts (USA), capable also of modelling a variety of physics phenomena, ranging from structural to magnetism problems. It was used to generate 3D meshes for the studied geometries, and to solve the fluid dynamics and thermal problems, with the SolidWorks Flow Simulation package.

III.III Shelter designs for meteorological stations

The shelter is a structure that serves as support for the instruments and sensors in a meteorological station, and that protects them from direct and diffuse solar radiation, precipitation, wind gusts, etc. The purpose is to ensure that the measurements taken by the sensors of the station match as close as possible the real values of the target atmospheric variables, avoiding large errors due to, for instance, the effect of solar radiation on the sensors, or overheating of the air mass within the shelter owing to inadequate ventilation.

In the market, there is a myriad of configurations and designs for shelters of meteorological stations. Next follow some examples of common designs [5]:

1. **Stevenson's shelter:** The main feature is that the lateral walls consist of a double structure of open vanes (like shutters). This is the most common shelter type for meteorological stations (see Fig. 3, left, and Fig. 4), and it is basically used for dry, humid, maxima and minima thermometers. A chimney is usually provided to ensure good ventilation of the interior.
2. **Generic shelter:** Any structure designed to protect the instruments and sensors, while ensuring adequate ventilation (see Fig. 3, centre).
3. **Pagoda shelter:** This shelter configuration is often used in polar zones. The double-layer roof configuration is designed to protect the instruments below the roofs from possible snow accumulation (see Fig. 3, right).

Wood is generally used for the construction of shelters because it is an excellent thermal insulator. Nevertheless, other materials are also used, like plastic, which though not being such a good thermal insulator at elevated temperatures, is less expensive, lighter, and more resistant to corrosion, and thus requires less maintenance. To counterbalance the deficiencies of plastic as a thermal insulator, stations with shelters made of plastic may include artificial ventilation, e.g., a small fan or blower which helps evacuating the excess heat within the station.

III.III.I Recommendations by the WMO

The WMO provides recommendations for shelter design, a few guidelines regarding appropriate locations

for placing meteorological stations, and requirements relating to ranges and acceptable errors when measuring relevant variables [6].

Basically, the WMO proposes two shelter designs:

Shelters for natural ventilation: These shelters should be made of wood, although plastic or other stiff materials may be suitable, too. The external and internal faces of the shelter should be painted with non-hygroscopic white paint to reflect solar radiation while preventing moisture absorption. The lateral walls should consist of a double structure of open vanes (like the Stevenson's shelter in Fig. 3, left). The floor should be made of wood strips placed alternatively in two different horizontal levels. In cold climates, due to the high reflectance of the snow, the shelter should have two floors. The shelter should have a double-layer roof, with the layers separated such that air circulation prevents overheating when the incident solar radiation is very intense. The slope of the outer-most layer of the roof should be adequate for water evacuation. To avoid direct incidence of sunlight on the instruments, the access door should be facing North in stations located in the northern hemisphere (see Fig. 4), while it should be facing South in stations located in the southern hemisphere. The design and dimensions of the shelter should be such that internal air circulation is good and overheating is minimized, while maintaining adequate distance between instruments and walls. The shelter should be kept clean and should be painted regularly, e.g., once every two years (or every year if the station is located in a highly polluted area). If the shelter incorporates artificial ventilation, the heating due to the ventilation system or electrical engine should be considered carefully.

Shelters for artificial ventilation: These shelters usually consist of two concentric cylindrical screens with vertical revolution axis. The material should be a thermal insulator, although polished metal to reduce absorption of solar radiation is also used. Airflow should circulate through the two screens (with a speed in the range 2.5 to 10 m/s) directed towards the dry thermometer, such that the temperature of the air surrounding the thermometer inside the station is close to the surface air temperature. The effect on temperature readings due to solar radiation heating the floor of the station can be mitigated by placing the thermometer well above the floor.

The WMO recommends stations to be placed at a height of 1.2 to 2 m, preferably in esplanades having short grass only, with no trees, buildings or other constructions in the vicinity. National weather services often provide extended and more detailed guidelines.



Fig. 3: Examples of shelter types for meteorological stations: Stevenson's shelter (left) [7]; generic shelter (centre) [8]; and Pagoda shelter (right) [5].

Finally, Table 1 shows requirements by the WMO relating to measuring range and maximum acceptable error for measurements of some relevant variables.

	Units	Range	Error
Atmospheric pressure	hPa	500-1080	± 0.1
Precipitation	mm/hour	0.02-2000	± 0.1
Solar irradiance	J/m ²	-	± 1
Temperature	°C	-30-45	± 0.1
Relative humidity ³	%	5-100	± 1
Wind direction	°	0-360	± 1
Wind speed	m/s	0-75	± 0.5

Table 1: WMO requirements on range and maximum acceptable error for measurement of ECV.

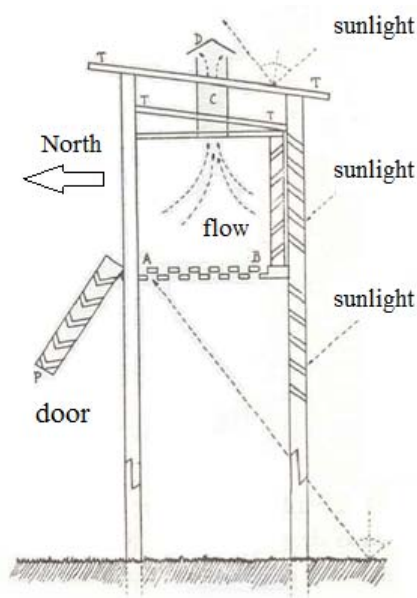


Fig. 4: Lateral view of a Stevenson's shelter correctly installed in the northern hemisphere [9].

III.III.II Studied shelter designs

Four different shelter designs have been studied: first, a design based on the recommendations by the WMO (shelter #1, the Stevenson's screen, described previously), followed by a smaller design with identical geometry (shelter #2, shown in Fig. 5). The objective was to assess the effect of the dimensions of the shelter on its performance. The reason was that the dimensions recommended by the WMO are relatively large, and thus it would be interesting to see if smaller dimensions (more convenient for reducing manufacturing costs) result in better performance. Namely, the dimensions for shelter #1 were approximately 909×580×560 mm³, while for shelter #2 the dimensions were approximately 685×200×200 mm³.

Two alternative designs to the Stevenson's shelter were analysed (shelters #3 and #4, shown in Fig. 6 and Fig. 7). These geometries follow some general features of the Stevenson's screen, i.e., double-layer floor, roof, and lateral walls. But, since the critical issue is ventilation for heat evacuation, they basically present a different configuration of the lateral walls and, particularly, the ventilation orifices. The objective was to assess the effect on the performance of these simpler configurations of the lateral walls. Finally, since shelter #2 performs better than shelter #1, as will be shown in Section IV.I, shelter #3 and shelter #4 were designed with similar dimensions to those of shelter #2. The maps of all the studied shelter designs can be found in Appendix A.

All four designs were simulated in three different materials (PVC, rubber and Iroko wood), with and without white paint coating. The objective was to assess the effect of both the material and the white paint on the performance. PVC was considered interesting due to its low weight and cost. Namely, a number of commercial

shelters at present day are made of PVC. Natural rubber was considered because there is a high number of old used tires, posing a challenge for waste management, as it takes a long time for rubber to degrade, polluting the environment in the process. If rubber proved to be a good material for mass production of low-cost shelters, this would be an interesting option for recycling tires. Finally, most shelters are made of wood, as it is a good thermal insulator, and thus wood was also considered in this research. In particular, a representative wood from Africa (i.e., Iroko wood) has been chosen for proximity to target customers of the meteorological station. Not having to import wood from distant locations to produce the shelters may reduce the manufacturing costs.

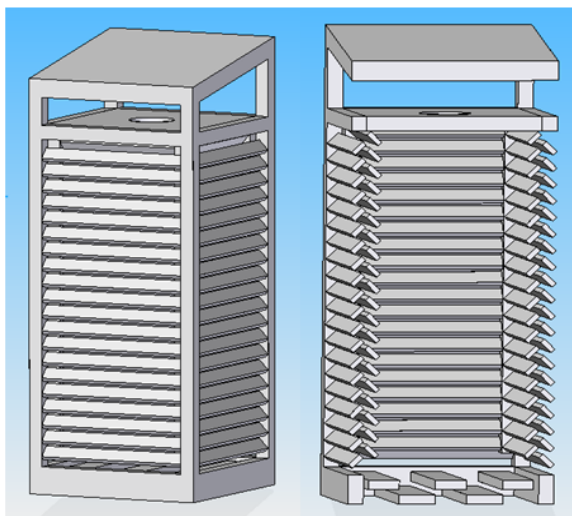


Fig. 5: 3D CAD view and cross-section of shelter #2.

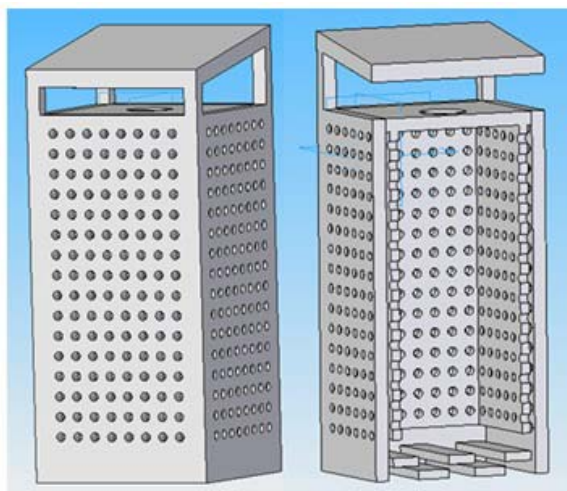


Fig. 6: 3D CAD view and cross-section of shelter #3.

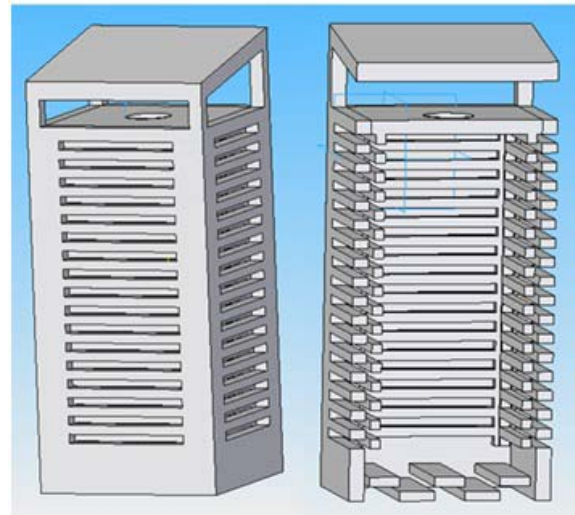


Fig. 7: 3D CAD view and cross-section of shelter #4.

III.IV Meshing

Once the geometries are generated, the next step in CFD analysis is meshing the fluid domain. In this process, the domain is discretized into a grid of small cells (e.g., with tetrahedral shape) where the Navier-Stokes equations will be solved. It is necessary a compromise between low grid density (causing low accuracy) and excessive computational cost. A common solution is to refine the grid only in regions where higher accuracy is desired, and/or where the properties vary significantly in small distances, and then to increase progressively the cell size as we move away from these regions. Nevertheless, refining the grid produces more accurate results generally only up to a given threshold, after which there is no significant change with cell size reduction. To identify such threshold, a mesh independence study is performed. Finally, attention must be paid when choosing the dimensions of the simulation domain, so that all fluid effects can develop properly. The size domain is increased progressively until simulation errors (e.g., reversed flow) disappear.

III.V Definition of the criterion to establish the goodness of a shelter design

In this work, the focus is placed on surface air temperature, and thus the criterion to establish the goodness of the studied shelter designs is the accuracy with which the surface air temperature is reproduced inside the shelter. For this purpose, after running the simulations, the temperature will be evaluated for shelter #1 in a reference point located in (-221, -237, -248) mm, and for shelters #2, #3 and #4 in reference points located in (-324, -320, 100) mm. These points are representative of a hypothetical position of the temperature sensor in the real meteorological station.

Therefore, we will affirm that the performance is better whenever the temperature in the reference point reproduces more accurately the surface air temperature.

III.VI Definition of the physics of the problem and the boundary conditions

Next follows a list of several input parameters that needed to be defined to perform the simulations with SolidWorks. These specifications were defined with the purpose of simulating the shelter performance in the most demanding scenario. From the perspective of measuring surface air temperature accurately in target developing countries, since the critical issue is heat evacuation to prevent overheating of the air mass within the shelter, leading to wrong temperature and humidity readings, extreme conditions of temperature and solar radiation were used in this research:

1. **Type of analysis:** Internal, to be able to see the evolution of the temperature inside the shelter.
2. **Incident solar radiation:** Defined by:
 - i. **Geographical location:** Sabha (Libya), at latitude 27° 02' North and longitude 14° 26' East. Libya was chosen as it features the highest temperature ever recorded.
 - ii. **Date and time:** July 15 at noon (12 LT).
3. **Properties of the fluid:** The properties of air.
4. **Properties of the shelter material:** PVC and rubber were already available in the materials database of SolidWorks. On the contrary, Iroko wood was not available, and thus its properties were introduced manually. The properties as used in this research are shown in Table 2.
5. **Optical properties of the studied materials and the white paint:** Table 3 shows the optical properties for white paint, PVC, rubber and Iroko wood, as used in this research. For PVC, the properties of white Tedlar[®] plastic were used [10]. For Iroko wood, no information was found, and thus optical properties of dark wood and oak were averaged. For white paint, we averaged typical values as found in the market [11].
6. **Temperature:** The surface air temperature was set to 45°C, while the initial temperature of the shelter was 20°C, with moisture of 20%.
7. **Boundary conditions:** A face of the analysed volume is defined as velocity inlet, simulating the air flow entering the analysed volume, and another one as pressure outlet⁴, for the flow to leave the analysed volume. The remaining faces of the volume, far enough from the shelter, are defined as walls.
8. **Wind speed:** Two different wind speeds were simulated, with no vertical component, to assess the effect of this parameter on performance: an almost no-wind condition and a moderately

strong wind condition (wind speed 2 and 10 m/s along the x -axis, respectively).

	Units	PVC	Rubber	Wood
Density	kg/m ³	1379	1200	700
Thermal cond.	W/m·K	0.16	0.15	0.10
Specific heat	J/kg·K	1004	1000	1081

Table 2: Properties of the materials used in this research for the shelter designs.

	Paint	Tedlar [®]	Rubber	Wood
Emittance ⁵	0.90	0.90	0.95	0.90
Absorptance ⁶	0.20	0.40	0.95	0.60

Table 3: Optical properties of the materials' surface used in this research for the shelter designs.

IV. RESULTS & DISCUSSION

In this section, the results obtained for the studied shelter designs are presented and analysed. First, the two geometries based on the recommendations by the WMO but in different sizes (i.e., shelters #1 and #2) are compared. Second, the three designs with similar small dimensions (i.e., shelters #2, #3 and #4) are compared.

IV.I Comparison of shelters #1 and #2

Table 4 shows the temperature in the reference point as obtained from the simulations, for shelters #1 and #2, in PVC, rubber and Iroko wood, in the almost no-wind condition and the moderately strong wind condition (wind speed 2 and 10 m/s, respectively).

Material	White paint	Wind speed	S. #1 [°C]	S. #2 [°C]
PVC	no	2 m/s	52.58	49.65
	yes	10 m/s	53.15	50.42
	no	2 m/s	47.32	47.25
	yes	10 m/s	48.10	46.71
Rubber	no	2 m/s	56.14	52.28
	yes	10 m/s	56.87	53.08
	no	2 m/s	47.45	45.93
	yes	10 m/s	48.49	46.63
Wood	no	2 m/s	52.27	50.43
	yes	10 m/s	52.76	50.12
	no	2 m/s	47.36	46.37
	yes	10 m/s	47.73	46.38

Table 4: Temperature in the corresponding reference point, for shelters #1 and #2, in PVC, rubber and Iroko wood, at a wind speed of 2 and 10 m/s.

From the results in Table 4, it is evident that, when the surface is painted in white, for both designs, in all materials and for both wind speeds, the temperature in the reference point is significantly lower (5.34°C in average), and particularly closer to the surface air temperature, compared to the case with no white-paint

coating. In general, the performance is better when the wind speed is lower. This is due to the high temperature of the ambient air, such that higher wind speeds (with the consequent higher heat transfer rates) lead to increased overheating, as a larger mass flow of warm air enters in the shelter. As per the shelter material, an interesting observation is that wood performs the best, but followed very closely by PVC, in all the studied conditions. A shelter made of rubber is by far the worst performing. Nevertheless, the differences come to a minimum when the materials are painted in white. Thus, we can affirm that the effect of the paint is dominant, and that the shelter material is not critical provided it is coated with adequate white paint. Finally, it is remarkable that, for shelter #2, in all materials and for both wind speeds, the temperature in the reference point is closer to the surface air temperature compared to shelter #1, i.e., the smaller design performs better in all the studied conditions. In particular, the temperature in the reference point for shelter #2 is in average 1.17 °C (3.03°C) lower with (without) white paint coating, compared to shelter #1.

IV.II Comparison of shelters #2, #3 and #4

Since shelter #2 performance is better than shelter #1, shelter #3 and shelter #4 were designed with similar dimensions to shelter #2. In this section, the performance of all the smaller shelters is compared to establish the best design. Table 5 shows the temperature in the reference point as obtained from the simulations, for shelters #2, #3 and #4, in PVC, rubber and Iroko wood, with the wind speed of 2 and 10 m/s.

Material	White paint	Wind speed	S. #2 [°C]	S. #3 [°C]	S. #4 [°C]
PVC	no	2 m/s	49.65	50.38	50.10
	yes	10 m/s	50.42	50.51	51.01
	no	2 m/s	47.25	46.96	46.92
Rubber	yes	10 m/s	46.71	47.15	47.26
	no	2 m/s	52.28	52.81	52.54
	yes	10 m/s	53.08	53.13	53.76
Wood	no	2 m/s	45.93	47.35	46.87
	yes	10 m/s	46.63	47.06	47.21
	no	2 m/s	50.43	50.29	49.84
	yes	10 m/s	50.12	50.32	50.64
	no	2 m/s	46.37	46.84	46.71
	yes	10 m/s	46.38	46.92	47.04

Table 5: Temperature in the corresponding reference point, for shelters #2, #3 and #4, in PVC, rubber and Iroko wood, at a wind speed of 2 and 10 m/s.

The main conclusions derived from the results in Table 5 are similar to those in Section IV.I. Again, when the surface is painted in white, in all studied cases, the temperature in the reference point is significantly lower (4.32°C in average), and particularly closer to the

ambient temperature of 45°C, compared to the case with no white-paint coating. For the same reason exposed in Section IV.I, the performance is also better when the wind speed is lower, e.g., the temperature in the reference point is in average 0.45°C lower. Again, wood performs the best, followed very closely by PVC, and rubber is the less appropriate. There is no significant difference in performance between the smaller shelter designs. In this sense, it is worth mentioning that shelter #2 shows the closest temperature value in the reference point to the surface air temperature, while the other two geometries perform a little less. Nonetheless, the alternative designs, and/or using PVC or rubber, might be more interesting if we consider also other criteria. In any case, as in Section IV.I, an essential conclusion is that coating the shelter with adequate white paint is critical in achieving the best performance. There is yet another important conclusion. A priori, shelter #1 was expected to perform the best. The reason was that a larger shelter volume implies a larger mass of air within the shelter and thus, for a same energy input from solar radiation, the air temperature would increase less compared to the smaller mass of air in the smaller designs. However, the results show that shelter #1 is the less performing. A plausible explanation is that another effect is dominant: the increased surface exposed to solar radiation by the shelter #1 causes a comparatively increased warming respect to the smaller shelters. Fig. 8 shows the temperature contour plot for the less performing case (highest observed temperature in the reference point, 56.87°C): shelter #1, in rubber, with no white paint coating, for wind speed 10 m/s. Fig. 9 shows the temperature contour plot for the most performing case (closest value to the surface air temperature, 46.37°C)⁷: shelter #2, in Iroko wood painted in white, for wind speed 2 m/s.

V. DATA STORAGE & TRANSMISSION

Acquired data should be useful, of course, but also transparent and accessible to all at the minimum cost, and should be uploaded on the internet in real time, or with high frequency. See Appendix B and Table 1 for more details on data requirements. Several methods for storage and transmission of the ECV data acquired by the proposed station are being studied:

1. Data transmission to laptops/PC by Wi-Fi:

Advantages: advanced data management technologies and wireless data transmission technologies between devices or networks of devices are available. Disadvantages: need for data storage capabilities (data loggers); need for short station-to-laptop distance and maybe energy supply (for a 100 m range, need for 220 V electric supply); and an operator should visit the station frequently (e.g., on a monthly basis).

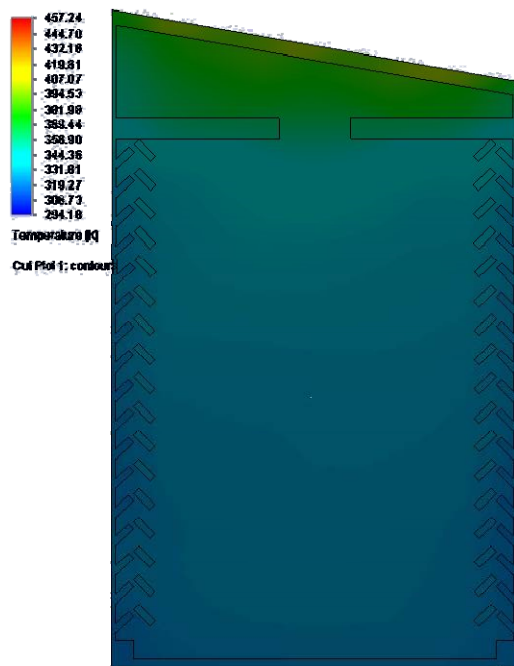


Fig. 8: Temperature contour plot for the less performing case: shelter #1, in rubber, with no white paint coating, for wind speed 10 m/s.

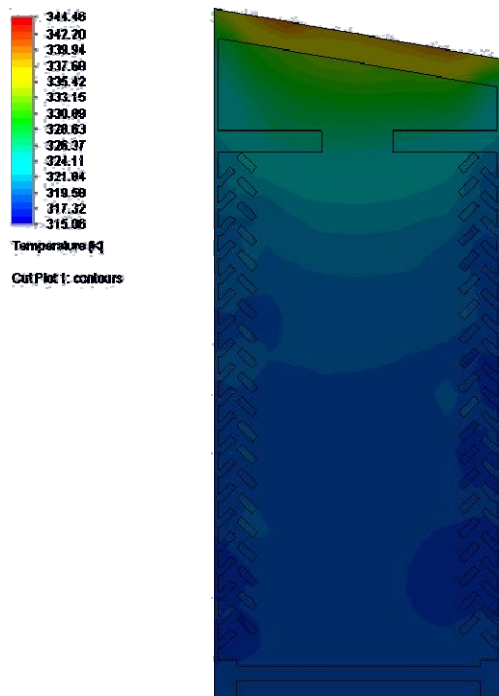


Fig. 9: Temperature contour plot for the most performing case: shelter #2 in Iroko wood painted in white, for wind speed 2 m/s.

2. **Data transmission to laptops/PC by Ethernet cable:** Disadvantages: need for data storage capabilities (data loggers); need for direct station-to-laptop cable connection and maybe energy supply; and an operator should visit the station frequently (e.g., on a monthly basis).
3. **Data transmission directly to the web by means of a mobile telephone:** Advantages: acquired data could be uploaded on the internet in real time or almost; and second hand mobile phones could be recycled for this purpose. Disadvantages: may need for energy supply.

In any case, the design of the station should aim also at a maximum degree of autonomy and endurance, bearing in mind possible locations where no energy infrastructure is available, or location to which access is not trivial or when operators are required to travel long distances. For energy supply, use of batteries, solar panels, etc. should be carefully considered.

VI. CONCLUSIONS

A new concept of meteorological station is proposed, especially designed for (but not limited to) developing countries, and to meet the requirements and standards of the international scientific community and international organizations making research on the Earth system and climate change monitoring. The station would measure in situ a set of ECV, valuable for many sectors of human activity. Namely, the data may: 1) enable a breakthrough in agriculture in countries lacking meteorological infrastructure and weather data [1]; 2) help in climate change monitoring, by bridging gaps in ECV observation and enabling calibration of satellite-based observations [3]; and 3) ease the diffusion of wind energy, and thus facilitating access to energy in areas lacking energy infrastructure, for example. This work presents, on one side, a pre-feasibility analysis of the proposed station, from which it is concluded that it may feature a competitive advantage respect to equivalent commercial stations in large markets like developing countries, or in particular applications, like networks to monitor climate change. An idea to explore more in-depth is that the station be supplied by a social enterprise. On the other side, this document reports a research to establish the best shelter design, as a first step. The criterion is the accuracy with which the surface air temperature is reproduced inside the shelter in extreme temperature and solar radiation conditions. A design based on recommendations by the WMO and a smaller design with identical geometry were analysed. Two alternative small designs were studied. All four designs were simulated in PVC, rubber and wood, with and without white paint coating.

The main conclusions of this research are:

1. The smaller shelters perform better than the shelter based on recommendations by the WMO (shelter #1). An explanation is that the increased surface exposed to solar radiation by shelter #1 causes comparatively higher warming.
2. The design based on recommendations by the WMO but in smaller dimensions (shelter #2) is the best performing.
3. A shelter made of wood leads to the best performance compared to PVC and rubber.
4. The performance is better when the wind speed is lower. This is due to the high temperature of the ambient air, such that higher wind speeds lead to increased overheating.
5. The influence of the shelter material, dimensions and design on performance is significantly smaller than the effect of the white paint coating. Thus, the former parameters are not critical provided the shelter is coated with white paint.
6. Shelters made of PVC or rubber instead of wood, and/or in alternative designs, are probably more interesting if other criteria are taken into account, like whether they make more sustainable, easier and/or cheaper logistics, manufacturing, etc.

VI.I Future work

Next follows a list of identified future work:

1. In direct relation with the shelter design: find the optimum dimensions allowing the shelter to encapsulate all necessary equipment while maximizing performance; simulate a design with no double structure of lateral walls and floor, aimed at reducing the manufacturing complexity and cost; and consider alternative scenarios, with different values of temperature, humidity, wind speed/direction, and solar radiation.
2. Realization of a feasibility study.
3. Research for support to improve any step in the full development chain including design, product development, prototyping, testing, manufacturing processes, etc.
4. Fund raising.
5. Further study the facilitation of acquired data to the international community.
6. Design and construction of a prototype to more precisely establish the costs of manufacturing the proposed station.
7. Elaboration of a business plan.

APPENDIX A – MAPS OF SHELTER DESIGNS

The maps of the studied shelter designs are shown at the end of this document.

APPENDIX B – DATA REQUIREMENTS

The needs for climate data and information have been manifested by Parties of the UNFCCC. Like many international organizations, these Parties have addressed the needs and priorities in relation to observations, in particular in developing countries, as limited progress in filling in situ observation gaps has been noted in these countries. In general, there is agreement in the following data requirements [3]:

1. Data should be accessible to all: data should be fully and openly accessible at the minimum cost and available with the minimum time delay.
2. Data should be useful: For this purpose, data should be standardized, robust and ready-to-use.
3. Data should be transparent: Transparency should be granted through data access policies in agreement with GEOSS Data Sharing Principles.
4. It is critical that decision-makers have high confidence in the integrity of the information and in its origin. Therefore, traceability indicators describing the information and its origin (in terms of requirements, data, processing methods and models) should be defined, and benchmarking approaches should be applied

The GEOSS 10-Year Implementation Plan, endorsed by almost 60 governments and the European Commission at the 2005 Third Earth Observation Summit in Brussels, explicitly acknowledges the importance of data sharing in achieving the GEOSS vision and anticipated societal benefits. The Plan states that "The societal benefits of Earth observations cannot be achieved without data sharing" and establishes the following GEOSS Data Sharing Principles [12]:

1. There will be full and open exchange of data, metadata and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation.
2. All shared data, metadata and products will be made available with minimum time delay and at minimum cost.
3. All shared data, metadata and products being free of charge or no more than cost of reproduction will be encouraged for research and education.

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¹ The Global Climate Observing System (GCOS) Essential Climate Variables (ECV) are based on a priority list of variables to be observed systematically, in order to properly monitor the climate change. There are 45 ECV organized in categories of atmospheric, oceanic and terrestrial [13], [14].

² Limited progress has been achieved on in situ ECV data acquisition systems in developing countries and even a decline has been detected in some regions [15]. The United Nations Framework Convention on Climate Change (UNFCCC) has also noted limited progress in filling in situ observation gaps in developing countries. Finally, according to the Intergovernmental Panel on Climate Change (IPCC) there is a significant “lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries” [16].

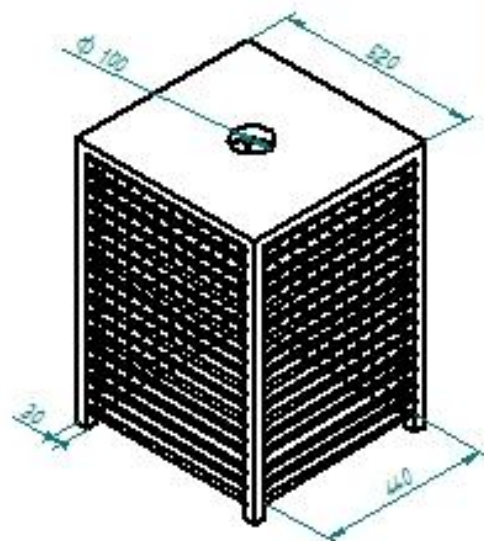
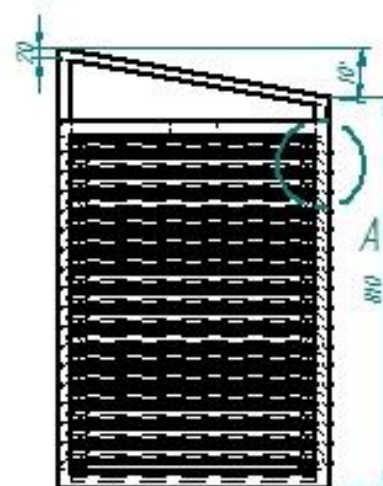
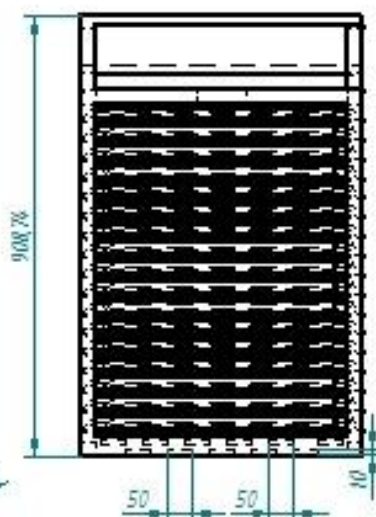
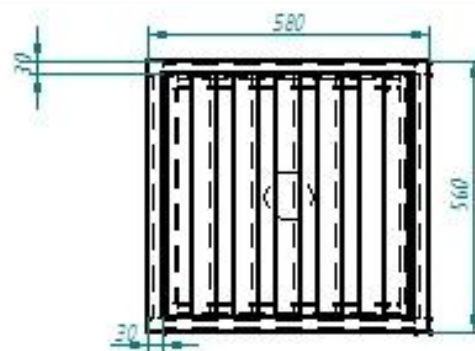
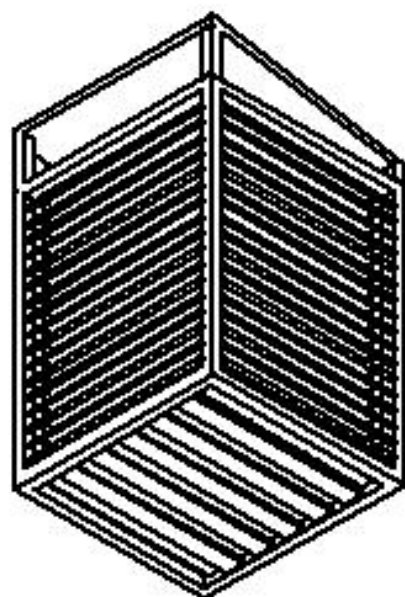
³ The relative humidity is the ratio of the partial pressure of water vapour in an air-water mixture to the saturated vapour pressure of water at a prescribed temperature.

⁴ The combination velocity inlet plus pressure outlet is recommended when working with incompressible flows, e.g., very low subsonic flows like in this problem.

⁵ The emittance or emissivity is the non-dimensional ratio of the electromagnetic radiant energy emitted from an object at a particular temperature and wavelength to the electromagnetic radiant energy that a blackbody (the perfect emitter) would emit at that same temperature and wavelength.

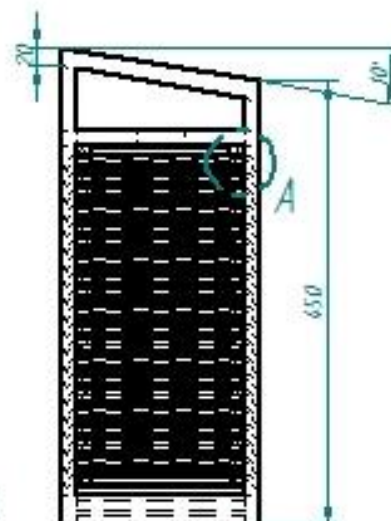
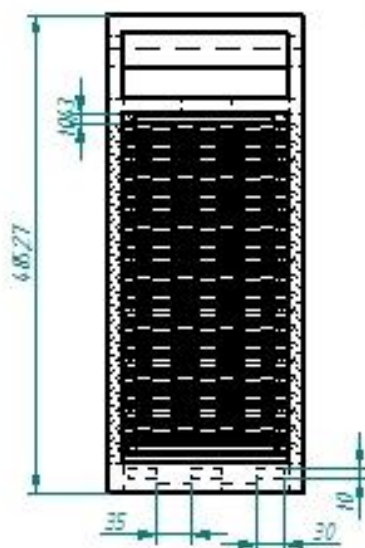
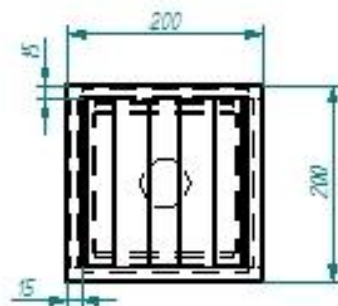
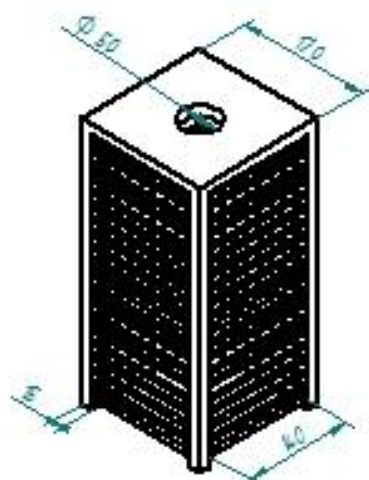
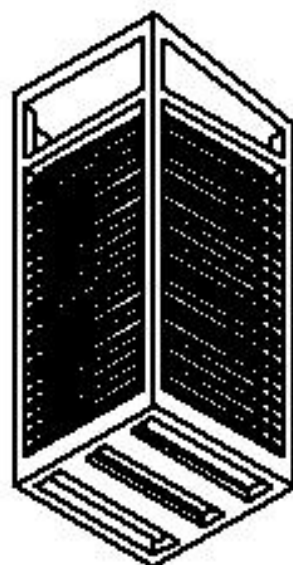
⁶ The absorptance is the non-dimensional ratio of electromagnetic radiant energy absorbed by a body to the total electromagnetic radiant energy incident on it.

⁷ Actually, the result with the closest value to 45°C occurs for a rubber-made shelter, but this is clearly out of the trends observed in all the other results, so it has been disregarded as it likely features large error.



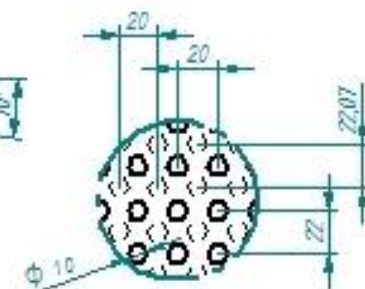
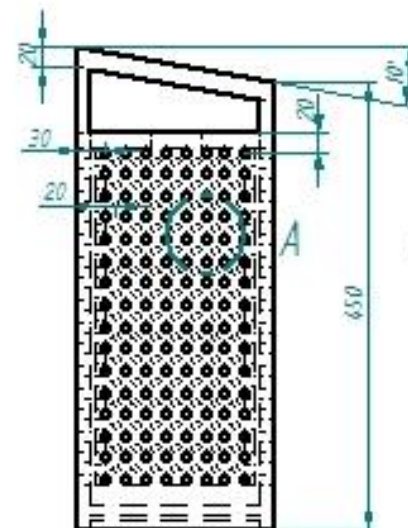
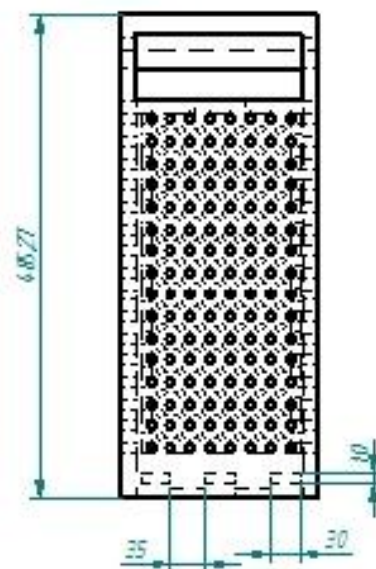
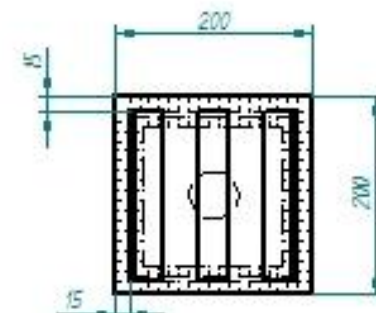
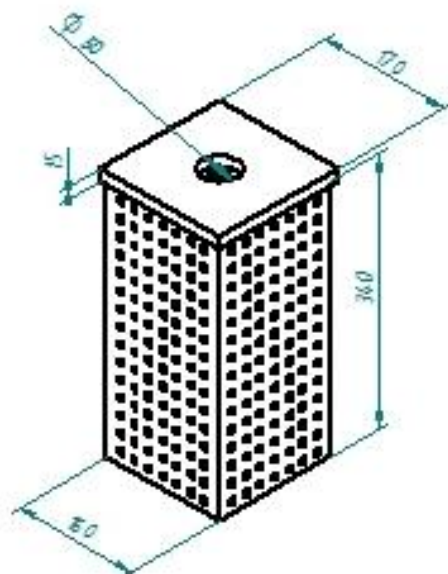
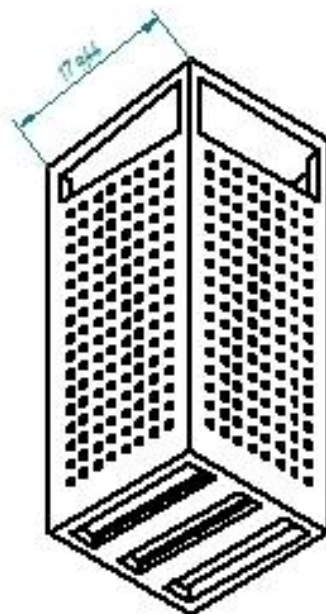
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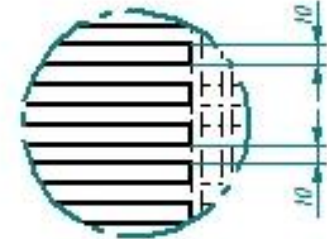
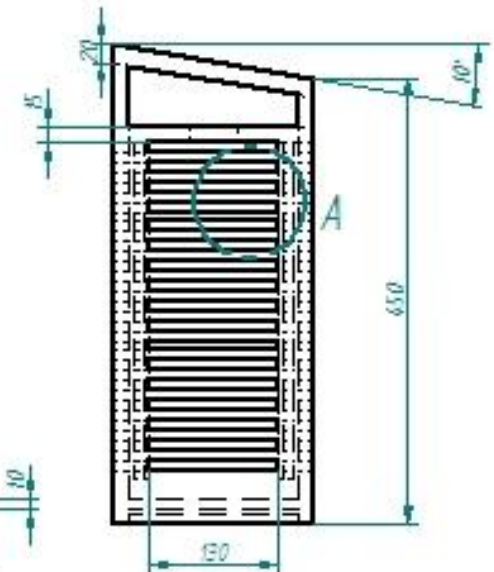
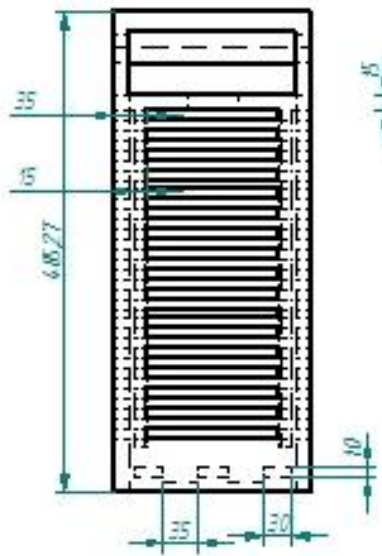
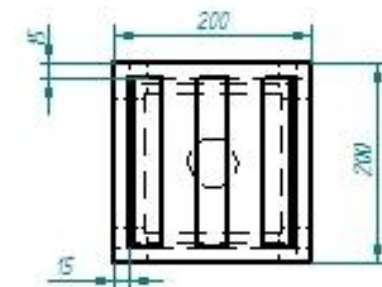
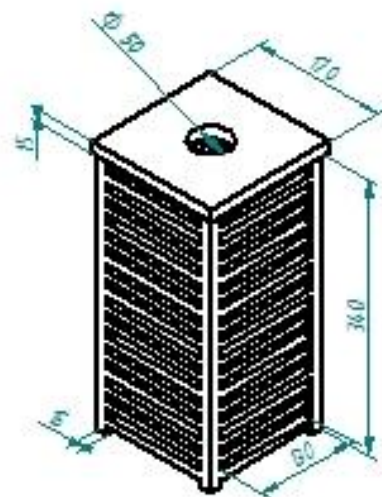
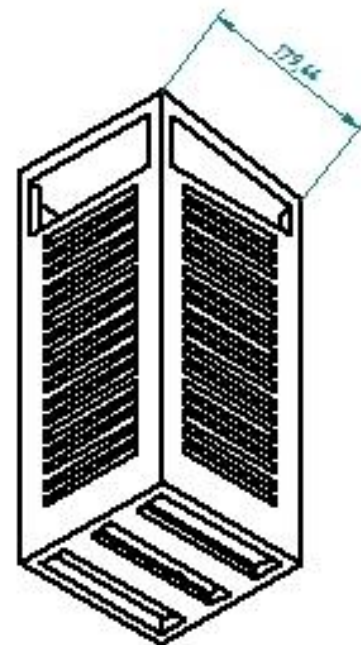
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Escala		Peso	Rev	



DETALLE A

Revisões			
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Aprova do 2			
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Escala		Folha	



DETALLE A

Revisões			
Rev	Descrição	Feito	Aprova do

Desenhado	Nome	Feito	SOLID EDGE EDS-PUM SOLUTIONS	
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Salvo indicação em contrário cotas em milímetros ângulos em graus tolerâncias $\pm 0,5$ e ± 1			A3	Plano
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